

422 Rec'd PCT/PTO 31 MAR 2000

Method for determining and controlling the material flow of
continuous-cast slabs

A Background of The invention
Description
^ Field of the Invention

The invention relates to a method for determining and controlling the material flow of continuous-cast slabs, in particular steel slabs, by monitoring and optimizing the temperature on their transport path between the continuous-casting installation and the rolling mill.

A Description of the Prior Art
For the operator of a continuous-casting installation

A with ^a connected rolling mill ¹ and ~~for~~ projecting slab continuous-casting finishing bays as a link between the continuous-casting installation and the rolling mill, it is becoming increasingly important to know the heat content which is present in the slab which has just been cast or is being temporarily stored, in order to bring the slab into a material flow which corresponds to the heat content still present therein in an economical optimum manner. Since a slab which has just been cast has an inhomogeneous temperature profile which, over a prolonged period, strives to achieve a more homogenous temperature profile, it is not possible to draw conclusions about the mean slab temperature using measurable surface temperatures. Therefore, it is also impossible to be certain of the slab temperature profile

003240-2096660

after a certain time, for example in order to bring the slab to an optimum, homogenous rolling temperature via a reheating fixture. Finally, the solidified slab which leaves the caster passes through different transport and processing paths, which each lead to different slab temperature profiles. Differences in the temperature profile arise depending on whether the slab is transported on a roller table with or without thermal insulation, whether one or more slabs are stored in the stack, whether the slabs are stored in an open slab yard or in an open or closed holding pit. Different temperature profiles also result for slabs which have undergone accelerated cooling in a water immersion basin compared to those which have undergone slower cooling in a water-spraying installation. It is therefore clear that it is desirable to find and be aware of the cooling profile of the various slabs, in order to use this knowledge in a targeted manner for material monitoring and controlling the material flow, which were hitherto carried out predominantly on the basis of experience and tests.

Summary of The Invention

In view of the above problems, the object of the present invention is to find a method for determining and controlling the material flow of continuous-cast slabs, in particular steel slabs, which enables the amount of heat and the temperature profile of a continuous-cast slab on its path between the continuous-casting installation and the rolling mill to be determined and used in a targeted manner, ~~in order~~

A *The*
~~for the values~~ found to be used in an existing
slab slab-monitoring system, ~~in order~~ to obtain a material flow
A which is optimum in terms of energy, i.e. is economical and
safe.

A To achieve the object, it is proposed, according to
A the invention, that ~~to determine~~ the amount of heat and the
slab is determined by temperature profile of the ~~slab~~, starting from the known
temperature of the liquid phase at the mold exit of the
continuous-casting installation and given knowledge of the
calculating physical parameters of the slab, the convective mixing of the
A amount of heat contained in the slab and the time-dependent
heat loss from the inhomogeneously cooling slab to the
surrounding medium ~~are calculated~~ by means of a mathematical-
using physical model, and ~~the~~ result of the calculation, if
A appropriate together with the measured surface temperature of
the slab, ~~is used~~ to control the material flow in an existing
A slab-monitoring system.

The proposal of the invention makes it possible to
guide a slab in a controlled manner through the various
material flows, such as warm charge rolling, hot charge
rolling, cold charge rolling or hot direct rolling, from the
continuous-casting installation into the rolling mill. It is
possible both to find the cooling profile of various slabs in
the stack and to determine the profile of cooling at the
surface of various slabs, in order to draw a conclusion
concerning the temperature in the interior of the slab using

control measurements. The calculated values and additional production data of the installation can be used, for example, to determine the size of the holding pit and, in operation, to predict hot batches at different mean temperatures.

A In a preferred configuration of the method according to the invention, ^a ~~there is provision for the~~ two-dimensional finite element method ^{may} ~~to~~ be used to calculate the mathematical-physical model. Finite element calculation methods enable a very wide range of operations to be simulated, thus assisting with design developments, handling operations, sales and, in the present case, also the future plant operator. In the ^{finite element calculation} design phase, the method is frequently used to reveal and minimize possible risks through structural mechanics analyses. It can be used to carry out deformation and stress analyses, temperature calculations, thermomechanical simulations and also to determine ^{finite element calculation} eigenfrequencies and eigenforms, with the aim of structural optimization. Simulations based on finite element calculations are often demanded by plant operators as early as the project phase and are frequently included in the supply contract of the plant as a fixed component of the contract.

Calculations using the finite element method are also carried out during the development of mathematical-physical models which have to provide accurate results on-line within

For the present invention, ^{may comprise} the two-dimensional finite element method, the finite difference method or software using formulae derived from off-line studies are used to calculate the mathematical-physical model.

The physical parameters of the slab used are preferably the temperature-dependent material values density ρ , the specific heat c_p , the thermal conductivity λ and scale properties.

material flow in the slab-monitoring system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention advantageously makes it possible, b

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The invention advantageously makes it possible, by means of the mathematical-physical model ^{which} preferably ^{uses} a finite element simulation or finite difference method, to

determine the temperature profile of slabs and stacks of
slabs of different dimensions under specific cooling
conditions. Through evaluation of the profiles of the mean
slab temperature and selected surface temperatures over time,
it is subsequently possible to ^{estimate} ~~make a good estimation~~ of the
mean slab temperatures by measuring the surface temperature. ^{present}

For example, the result of the method according to the
invention ^{may} ~~can~~ be used to ^{determine} ~~draw conclusions as to~~ how many
hours a fixed mean slab temperature is maintained in the
finishing bay. ^{Further} it is possible to ^{determine} ~~draw conclusions concerning~~
the entire temperature spectrum in the slab-monitoring
system. It has emerged that the method according to the
invention and the above-described calculation method are very
flexible in use and are suitable for achieving the object of
the invention, i.e. that of enabling economical and reliable
material flow between the continuous-casting installation and
the rolling mill. The invention ^{Replaces} ~~is able to replace~~ the

previous slab control method which was based on experience
and empirical values. The ^{continuous-casting} ~~installations~~ no longer have to be
overdimensioned for safety reasons, because with the method
according to the ^{present} ~~invention~~ it is now possible to determine
and control the actual conditions for the material flow
between continuous-casting installation and rolling mill.

The ^{invention method} ~~invention~~ is easiest to explain with reference to
a practical example. In the example, it is assumed that a
plurality of continuous-cast slabs are stored in a stack in

an open holding pit. The mean cooling profile of the various slabs in the stack is to be determined, as is the profile of cooling at the surfaces of various slabs in the stack. The ~~aim of an application could be~~ ^{inventive method may be used} to determine the size of a holding pit or to predict hot batches of slabs at different mean temperatures during ongoing production.

Working on the basis of a model as described above, ~~by way of~~ ^{the includes} example ^{discrete} thirteen slabs each with 420 ^{discrete} elements ^{are} discretized. It is sufficient to model one half of a slab given symmetrical boundary conditions and, for example, to generate the finite element network in such a way that the mean temperature and the time-dependent control of the stacking operation can subsequently be determined with ease.

The simulation can be divided up as follows:

1. Monitoring of the temperature of the slab cross section as it passes through the caster, corresponding to the starting temperature profile for each individual slab at the start of the stack.
2. Simulation of the stack of the individual slabs.
3. Simulation of the cooling of the stack of slabs.

In the first substep, the solidification of the slab in the caster is simulated in order to generate an entry temperature profile of the slabs in the holding pit which ~~is~~ ^{approximates the actual value} ~~close to reality~~. The material density, specific heat and thermal conductivity are temperature-dependent.

In the liquid phase, there is also convective heat exchange, but this was not modeled. In order nevertheless to simulate the temperature homogenization on the basis of the convective mixing, instead the thermal conductivity was increased by a factor of 100 compared to the solid phase. The various water cooling operations in the areas of the primary and secondary cooling zones represent important boundary conditions. The temperature range of possible surface temperatures is divided into sections of various heat transfer types (stable film evaporation, unstable area, burn-out point, etc.) on the basis of a heat transfer model, since different approaches apply with regard to the heat transfer coefficient for these areas. In some of these areas, the heat transfer coefficient is also dependent on the materials value of the surface of the cooling body, this applying, in the present case, in particular to highly oxidized surfaces, for which the materials values of scale are to be used.

The simulation of the stack of slabs begins with the introduction of the first slab into the holding pit. Thereafter, every 60 seconds the next slab is stacked on top of the previous slab. The stacking operation ends when a cold slab is laid on top of the twelve slabs which have hitherto been stacked. The inherent weight of the cold slab reduces the curvature of the top hot slab.

1. The first part of the paper is devoted to a review of the literature on the topic. It starts with a general overview of the field, followed by a more detailed discussion of the specific issues at hand. The author then presents his own findings, which are based on a series of experiments. These findings are then compared with the results of previous studies, and the author discusses the implications of his work. Finally, the paper concludes with a summary of the main points and some suggestions for future research.

The air convection is calculated using specific functions, since different heat transfer coefficients apply for the horizontal and vertical surfaces. At high temperatures, these coefficients are still low compared to the heat transfer coefficients of radiation, but at low temperatures the convection coefficients become dominant. Furthermore, the ambient temperature throughout the wider environment of the hall and the walls of the holding pit form part of the calculation. However, in a representative stack, these parameters can only be seen in a particular part of the solid angle, while in other parts of the solid angle there are adjacent stacks, which are at a similar temperature.

The bottom horizontal surface of the stack is in contact with the pit floor. The pit floor itself could be included in the finite element calculation, but in a simplified version it is also possible to model the pit floor as a semi-infinite body which remains constantly at its starting temperature, at which there is then a time-dependent heat transfer coefficient.

For given slab dimensions, it is then possible to determine the temperature profile over the cross section of the slab or the stack of slabs. To be reintegrated into the material flow between caster and rolling mill, the mean temperature of a steel slab should lie between 500 and 600°C. At the start of cooling, the first slab still has the temperature profile corresponding to when it leaves the caster. At the end of the stacking operation, it is found that there is a more homogenous temperature distribution in the stack if the floor is appropriately well insulated. As a result of the cold slab being laid on top, the top slab in the stack loses a relatively large amount of heat in the first hour, and the bottom slab in the stack cools rapidly during a short initial period, until the floor acts as an insulator.

By linking a physical-mathematical model to the automation of a standard slab material flow, the method according to the invention makes it possible to control the individual slabs between continuous-casting installation and

rolling mill in an economical and reliable manner. By carrying out control measurements on the surface of the slabs, including the values obtained through the calculation model, it is possible to draw conclusions as to the amount of heat and the temperature profile of the slab in a simple manner, provided that the appropriate boundary conditions are included. In this way it is possible to determine, at any location between continuous-casting installation and rolling mill and, in particular, in storage yards, how much heat is associated with the particular slab and what level of energy has to be supplied or dissipated in order to reach the temperature profiles which are optimum for the further process. The invention provides a design engineer with a means of designing the installation optimally, so that it is economical to produce and run.